

WHAT DOES NEUROSCIENCE AND COGNITIVE PSYCHOLOGY TELL US ABOUT MULTIPLE INTELLIGENCE

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ABSTRACT

Studies that have used noninvasive brain imaging techniques to record neocortical activity while individuals were performing cognitive intelligence tests (traditional intelligence) and social intelligence tests were reviewed. In cognitive intelligence tests 16 neocortical areas were active, whereas in social intelligence 10 areas were active. These results suggest that, at least for tasks reviewed in the present study, more neocortical activity was required for the performance of cognitive intelligence tests than social intelligence tests. There was considerable overlap in the areas which were activated in cognitive and social intelligence, suggesting that both types of intelligence may rely on neural processing in similar cortical areas. Processes which may be comparable in cognitive and social intelligence include short-term memory, long-term memory, response inhibition, sustained attention, and perceptual speed and accuracy. Implications of the findings were considered in terms of validation of multiple intelligence and future directions in education.

Keywords: Multiple Intelligence, Neocortex, Cognitive Intelligence, Social Intelligence, Cognitive Psychology.

INTRODUCTION

A test that was developed to predict school achievement of low performing children in school eventually evolved into the first intelligence test (Binet & Simmon, 1905). Binet did not test what might have been taught in school, but focused on abilities such as memory, attention, understanding, similarities, and differences. Spearman (1904) suggested that intelligence consisted of a single, primary, general (g) intelligence, but in the 1930's more advanced statistical techniques began to reveal that intelligence was composed of more than one factor. Thurston (1937) suggested that intelligence was composed of verbal, perceptual speed, number, rote memory, world fluency, deductive reasoning, inductive reasoning, and spatial visualization. The list of potential types of intelligence has continued to grow, and Gardner (1998) proposed that the following should be included in intelligence: linguistic, logical-mathematical, musical, spatial, body-kinesthetic, interpersonal, intrapersonal, and naturalistic. Gardner also considered the possibility of including spiritual and moral intelligence. The list of

potential types of intelligence has recently expanded into areas outside the domain of cognitive intelligence. For example, social and emotional intelligence have, in particular, captured the attention of the scientific community and the general public (Lam & Kirby, 2002; Ochsner & Lieberman, 2001; Goleman, 1995). Thus, in approximately the last 100 years, the types of intelligence have greatly increased and have expanded into areas other than cognitive intelligence. Given the current trend in considering additional types of intelligence, it appears likely that more types of intelligence will be considered in the future. If the field of intelligence continues to expand in this direction, one might conclude that the age of multiple intelligence has begun.

Recently developed brain imaging techniques are particularly useful for identifying brain areas that underlie the neural processes for various forms of intelligence and for examining brain areas involved in performing lower level processes which are important for intelligence (Jung & Haier, 2007; Cabeza & Nyberg, 1998). Comparing the similarities and differences in various brain areas during

performance of different types of intelligence tests would provide important information regarding whether similar or different brain areas are active in different types of intelligence. For example, activity in different brain areas during performance of different kinds of intelligence would provide validation that there are separate forms of intelligence. Neural activity in comparable brain areas during performance of tests which are thought to measure different forms of intelligence would provide evidence that the tests are actually measuring similar forms of intelligence. Relating activity in specific brain areas to the functions which the areas are thought to perform would provide relevant information regarding the underlying brain process for various components of intelligence.

The major purposes of the present paper were to review papers that have used neuroimaging techniques to investigate brain areas that are active in cognitive intelligence and social intelligence. Cortical activity was related to the types of behavioral functions which brain areas are thought to perform, and implications of the findings were considered in terms of validation of multiple intelligence and for future directions in education.

Cognitive Intelligence

The advent of the cognitive revolution in the 1960s, in conjunction with suggestions that intelligence consists of a number of separate components, led to a modern stage in intelligence research in which cognitive intelligence was considered in terms of lower level cognitive processing (Hunt, 1982; 1983). For example, intelligence was parsed into fluid intelligence and crystallized intelligence. Fluid intelligence consists of relatively culture free mental processes that could generally be used in a large number of situations to solve problems. In terms of cognitive processes, lower level processing, such as short-term memory, working memory, and executive functions would be expected to contribute to fluid intelligence. These lower level cognitive process would also result in the transfer of information into long-term memory. Long-term memory is similar to the characteristic of crystallized intelligence. Crystallized intelligence consists of previously acquired skills and

knowledge that are dependent on being exposed to the general environment. Cognitive processes for crystallized intelligence include recognition, long-term memory, and retrieval from long-term memory (Colom, Jung & Haier, 2007; Colom, Abad, Quiroga, Shih, & Jlores-Mendoza, 2008).

Several studies have found a close relationship between short-term memory, working memory, and intelligence (Colom et al., 2007; Colom et al., 2008). Short-term memory tasks are characterized by simple memory span tasks which involve remembering lists of words or numbers for a short period of time, generally without any distracter tasks. Working memory is defined by more complex memory span tasks in which participants must also count when items are presented, or the participants are required to recall, for example, every fifth item in the list. Rehearsal is a major cognitive process used to store information in short-term memory, whereas working memory tasks require both rehearsal and shifts of attention back and forth between to-be-recalled items and the distracter task. Colom et al. (2008) reported that mental speed, mental updating, and control of attention were not consistently related to working memory, and that when the short-term memory component was removed from mental speed, mental updating, and control of attention, neither mental speed, updating, or control of attention were related to intelligence. On the bases of these findings, Colom et al. (2008) suggested that short-term memory is the basic ability which supports working memory and executive functions. Since short-term memory processes are important for fluid intelligence and crystallized intelligence, it appears that short-term memory processes may provide the bases for many forms of both academic performance and intelligence.

Imaging Cognitive Intelligence

A major review of neuroimaging studies of cognitive intelligence provided activity data from 10 positron emission tomography (PET) studies and 17 functional magnetic imaging (fMRI) studies for the same 16 neocortical areas (Jung & Haier, 2007). The cognitive intelligence tests included measures of fluid intelligence, crystallized intelligence, and cognitive reasoning. The

active cortical areas from this review are presented in Figure 1. Areas that were involved in early sensory processing and motor output were not included in Figure 1, because these processes are unlikely to be involved in intelligence processing. Due to space limitations, only data from the left hemisphere were included.

In Figure 1 active areas during cognitive intelligence test performance were represented by horizontal lines overlying a drawing of the left hemisphere of the human neocortex. The numbers on the drawing refer to Brodmann's areas (BA). Brodmann defined neocortical areas according to the neuronal organization of the human neocortex and provided numbers for areas that differed according to the neural organization. Brodmann's classification has remained the most commonly cited method for differentiating areas of the human neocortex. Although BA were initially differentiated by neural organization, the separate areas are now known to also represent areas involved in rather specific brain functions.

As in Figure 1, a total of 16 brain areas were active during cognitive intelligence test performance. Broad areas of the prefrontal cortex (BA 44, 46, 47, 45, 6, 8, 9, and 10), parietal cortex (BA 40, 7, and 39), and the temporal cortex (BA 20, 21, 22, and 36) were active during cognitive intelligence test performance.

Prefrontal areas are thought to be involved in various

cognitive processes, such as short-term memory, working memory, and elaborative processing (Fuster, 1997; Gazzaniga, Ivy, & Mangum, 2009). Recent imaging studies (Cabeza & Nyberg, 1998) have revealed that performance of short-term memory tasks and working memory tasks increased activity in prefrontal areas (BA 44, 45, 46, and 9) which are also active while performing cognitive intelligence tasks. These findings suggest that large areas of the prefrontal cortex are involved in processing information in short-term memory and working memory and, as pointed out above, these processes contribute to fluid intelligence.

Areas 20, 21, and 22 in the temporal lobe appear to be involved in the consolidation of memory into long-term memory, long-term storage of memories, and retrieval of information from long-term memory (Gazzaniga et al., 2009). Given that crystallized intelligence involves knowledge of information that has previously been obtained from experiences in the general culture, and that temporal areas are involved in storing this type of information, it appears that the high neural activity in temporal areas are related to crystallized intelligence.

Areas 7 and 40 in the parietal lobe were among the active areas during performance of cognitive intelligence tests. These parietal areas are known to have large reciprocal interconnections with areas in the prefrontal cortex that are also active during cognitive intelligence performance (Fuster, 1997). These interconnections suggest that there would be a considerable interaction between prefrontal and parietal areas. Brain imaging studies have revealed that parietal areas 7 and 40 and prefrontal area 9 were active during sustained attention (Cabeza & Nyberg, 2000). Therefore, areas of the parietal and prefrontal cortex may be involved in the sustained attention which is required for the performance of cognitive intelligence tests.

The two major language areas of the neocortex, Broca's area (the more ventral areas of BA 44) and Wernicke's area (the more ventral areas of BA 39 and posterior areas of BA 42), were active during the performance of cognitive intelligence tests. Broca's area is involved in the expressive aspects of language, which broadly defined

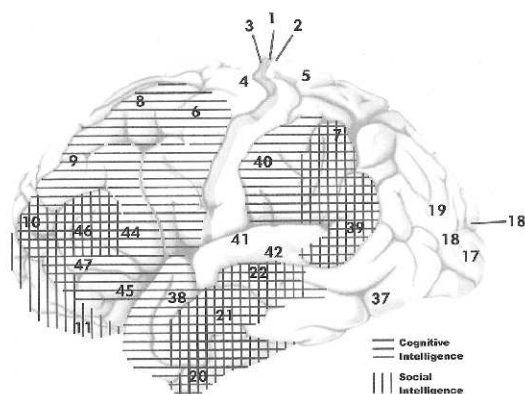


Figure 1. Neocortical areas that were active during performance of cognitive intelligence tests and social intelligence tests.

includes speaking and writing. Wernicke's area is involved in the receptive aspects of language, which includes understanding what is spoken to an individual and reading (Gazaniga, et al., 2009). Therefore, activity in major speech areas would appear to be related to the input of verbal material and the expression of this information during the performance of cognitive intelligence tests.

Social Intelligence

Social intelligence is becoming an increasingly popular concept in the general culture and in the scientific literature. Social cognitive neuroscience is a new and emerging interdisciplinary field that attempts to understand the brain areas that are involved in social behaviors and the neural mechanism that give rise to social behaviors (Ochsner & Lieberman, 2001).

Altruistic behavior and social exchange are apparently the only two paradigms that have been used to investigate brain activity during social behaviors. In altruistic situations individuals must learn to recognize individuals that have been cooperating with them or are failing to cooperate and choose to cooperate with those that cooperate and avoid cooperating with others that do not cooperate. There must also be resistance against obtaining short-term gains that may accrue by accepting, but not reciprocating with the actions of others. In social exchange, individuals must recognize the rules of social interchange and act in an appropriate manner. Engaging in social exchanges involves detecting risks and managing to avoid hazards that arise in social exchanges. It has been proposed that knowing the rules of social exchange and reducing the risks in social exchanges are separate functions (Ermer Guerin, Cosmides, Toby, & Miller, 2006).

Imaging Social Intelligence

The Prisoner's Dilemma task has been used by a variety of disciplines as a model of social relationships based on reciprocal altruism. In the Prisoner's Dilemma task two players independently choose to either cooperate with each other or to not cooperate, and each player is awarded a sum of money that depends on the

interaction of both players in that round. There are four possible outcomes in each round: player A and B cooperate (CC), player A cooperates and B defects (CD), player A defects and player B cooperates (DC), or both players defect (DD). The payoffs in each round are arranged such that $DC > CC > DD > CD$.

A recent fMRI study of individuals playing the Prisoner's Dilemma task revealed that during choices of two player's BA 11 in the prefrontal cortex was active (Rilling, Gutman, Zeh, Pagnoni, Berns, & Kilts, 2002). In reaction to other player's choices areas 7, 1, and 22 were more active (See Figure 1). These findings suggest that brain areas involved in making choices and reacting to the choices of others involve somewhat different brain areas. Mutual cooperation between players was associated with activation of brain areas that have been linked to reward processing (BA 11). The authors proposed that activation of BA 11 positively reinforces reciprocal altruism and motivates participants to resist the temptation of selfishly accepting favors but not reciprocating. Alternatively, cooperating may produce feelings of trust and comradery that are reinforcing. Thus, activation in medial prefrontal areas and orbitofrontal areas may be associated with positive emotions that arise from mutual cooperation.

Experiments on social reasoning and nonsocial precautionary rules have often used the Wason (1983) test. In the Wason task a story is provided to the participant, and a rational is provided for the rule. Each participant is informed that the rule specified whether the concern was about people cheating on the rule (social contract), breaking a safety rule (precaution), or simply violating the rule (descriptive). Following the story each participant was asked, "Could this person have violated the rule?" The participant's task was to determine whether a person in the story had violated the rule. Fiddick, Sampinato, and Grafman (2005) used the social contract rules and precautionary rules of the Wason in an fMRI study and found increased activity in social contract rules in the angular gyrus (BA 39), and the orbitofrontal cortex (BA 10; see Figure 1).

To examine the hypothesis that there are functionally

specialized systems for reasoning about social exchange and precautionary rules, Ermer et al., (2006) recorded fMRI data while participants performed the social rules and the precautionary rules of the Wason test (1983). Brain areas that were significantly activate during performance of social contracts included the temporal lobes (BA 20, 21, and 22). More importantly, social contact stories activated different areas than precautionary stories. There was significantly higher brain activity in the anterior temporal pole (BA 20), and middle temporal lobe (BA 21) in social exchange than precautionary rules. These findings suggest that social contract and precaution rules are interpreted via two functionally distinct, domain-specific cortical systems.

Comparing Cognitive and Social Intelligence

As in Figure 1, prefrontal areas 46, 11, and 10 were active in social intelligence tasks. Since BA 46 is thought to be a central area for short-term memory, working memory, and executive functions that underlie fluid intelligence, the involvement of area 46 in social intelligence may be related to the types of processing that is also required for fluid intelligence.

Prefrontal areas (BA 11, and 10) appear to be involved in inhibiting inappropriate behavior, guiding social responses, and complying with social rules (Fuster 1997; Gazzanagia et al., 2009). Areas 20, 21, and 22 may be involved in long-term memory process, and these memory processes may provide the bases for crystallized intelligence. Thus, activity in areas 20, 21, and 22 in social intelligence may be related to crystallized intelligence. However, neural imaging studies have revealed that temporal lobe areas BA 21 and 22 are active during language processing (Cabeza & Nyberg, 1998), also it is suggesting that temporal lobe activity during performance of cognitive and social intelligence tests may be due to the language requirements for performing cognitive intelligence and social exchange tasks.

Area BA 11 in the orbitoprefrontal cortex (see Figure 1) was the only area that was active in social intelligence but inactive in cognitive intelligence. This finding suggests that area 11 is uniquely involved in some aspect(s) of

social behavior. Neuroimaging has revealed that activity in the Area 11 increased when matching faces, identifying famous and nonfamous faces, detecting the differences between faces, and detecting gender differences (Cabeza & Nyberg, 2000). Since facial expressions are known to convey a great deal of meaningful information in social situations (Gazzaniga, et al. 2009), area 11 may be involved in social intelligence. Although the tasks used in the social intelligence experiments described above did not involved any aspect of faces, area 11 may be an area in which facial information and other social activities are integrated.

General Discussion

The degree of overlap in brain areas that were active in cognitive and social intelligence tasks was considerable. There was only one brain area (BA 11) that was active in social intelligence and inactive in cognitive intelligence, at the same time there were several brain areas (BA 10, 46, 7, 39, 22, 21, and 20) which was active in both cognitive and social tests. This high degree of overlap suggests that cognitive and social intelligence may actually be quite similar forms of intelligence. The finding was that several more cortical areas were active in cognitive intelligence than social intelligence which suggests that cognitive intelligence requires more neocortical processing than does social intelligence and that this processing is specific to cognitive intelligence. Results from brain imaging studies and cognitive psychology are likely to have important implications for a recently developed field which integrates the brain and educational practices (Battro, Fischer, & Lena, 2008). For example, if brain imaging studies continue to find that similar brain areas are active in both cognitive and social intelligence, education in cognitive processes that are important for high academic achievement would also be expected to have a positive influence on social intelligence. The high degree of overlap in brain areas which are active in cognitive and social intelligence also provides a possible reason why individuals with low cognitive abilities are also socially impaired.

As discussed earlier in this paper, cognitive processes, such as rehearsal and working memory, which provide the

bases of fluid intelligence are also important for transferring information into long-term memory or crystallized intelligence. In addition, recent research using advanced statistical procedures has revealed that short-term memory is the most basic and important strategy for cognitive intelligence (Colom, et al., 2008). Cognitive psychologists have also shown that rehearsal is a very important strategy for storing information in short-term memory and that in non-disabled learners these strategies gradually develop from the early school years to the middle to late teens (Swanson, 1987). In the ages from approximately 5 to 8 years of age, children with learning disabilities and non-disabled learners use a type of rehearsal referred to as single item rehearsal. With single item rehearsal only the most recently presented information is rehearsed. As non-disabled children mature, they start to use more cumulative rehearsal, which involves rehearsing the last item presented along with several previously presented items. By the middle to late teens cumulative rehearsal is a major cognitive strategy by which non-disabled learners store information. Unlike non-disabled learners, children with learning disabilities have been shown to be developmentally delayed in switching from single item rehearsal to cumulative rehearsal, and this developmental delay appears to be a major factor in learning disabilities (Swanson, 1987). These findings suggest that a developmental delay in acquiring effective cognitive strategies may play an important role in low academic achievement and intelligence.

Knowledge of the cognitive processes which develop from childhood to adolescence have important implications for educational practices. The bases for switching from single item rehearsal to cumulative rehearsal from the early school years to the middle to late teens is unknown, but it appears that during formal education non-disabled students learn to use more effective strategies which lead to higher school performance. These findings suggest that across the formal school years, students are "learning to learn." Therefore, an important goal for educators would be to teach the subject matter and teach children the basic

cognitive strategies that are used to achieve in school. Given the close relationship between academic achievement and cognitive intelligence, increased academic achievement may also increase cognitive intelligence. Since the results of the present study show that cognitive and social intelligence involve similar cortical areas, improvements in cognitive intelligence may also improve social intelligence.

In support of the suggestion that schooling increases cognitive intelligence, discovered that in 14 countries cognitive IQ increased from 5 to 25 points in a single generation. The most dramatic increase of 21 points in 30 years was founding using the Raven's Progressive Matrices which is often used in neuroimaging studies and is primarily a measure of fluid intelligence (Jung & Haier, 2007). In an extensive review of the literature, Ceci (1991) has shown that there is considerable evidence that schooling exerts a powerful influence on cognitive IQ. With regard to the time per sec in school (quantity), there is a positive relationship between the highest grade completed in school and cognitive IQ, and negative effects of delayed schooling, intermittent school attendance, and premature termination of schooling on cognitive IQ. With regard to the quality of schooling, relevant information provided in classes is likely to provide the necessary information for correct answers on fluid intelligence tests. Ceci suggested that schooling may also influence IQ performance indirectly by incalculating the various types of cognitive strategies that are necessary for both high performance in school and on fluid intelligence tests. Ceci estimated that the school factors that influence IQ range from 0.25 to 6.0 IQ points per year of missed schooling.

Although the findings reviewed above suggest that cognitive processes are important for academic achievement and intelligence, they have a major flaw; the data are correlational, and therefore only suggestive of the causal effects of cognitions on achievement and intelligence. Behavioral and neuroimaging data have apparently not yet been obtained in experiments in which a treatment designed to increase cognitive intelligence or social intelligence have intervened between a pre-test

and post test. Research examining baseline performance and brain activity, some form of educational training, and then a post test of performance and brain activity would be important, because the changes in behavior and brain activity from the pre-test to the post-test can be attributed to the educational training, i.e., the findings go beyond results from correlational studies. Although experiments designed to assess the influence of cognitive/educational training on intelligence and brain activity have apparently not yet been conducted, three recent studies have assessed the influence of cognitive/educational training on reading, spelling, and brain activity in dyslexic and nondyslexic children and adolescents (Aylward, et al., 2003; Richards, et al., 2006; Simos, et al., 2005). These studies revealed that prior to training both reading and spelling and brain activity in Wernicke's area (the ventral areas of BA 39 and the posterior portion of BA 42) and Broca's area (ventral areas of BA 44) were lower in dyslexics than in nondyslexics. However, after training reading, spelling, and brain activity in these language areas were similar in dyslexics and nondyslexics. The increased similarity was generally due to the increased performance and increased cortical activity of dyslexics. Given the fact that the cognitive/educational manipulations were only several weeks in duration, the possibility that genetic effects or developmental effects per se changed performance or brain activity is unlikely. The most plausible explanation is that the cognitive/educational treatments were responsible for both the increased performance and neocortical activity. The historical importance of these three studies should not be overlooked. These three studies are apparently the first to show that a fairly brief cognitive/educational experience can increase reading and spelling performance and increase neural activity in brain areas which would be expected to be involved in the performance increases.

Conclusion

The close relationship between neocortical activity during the performance of cognitive and social intelligence tasks suggests that to a large degree cognitive and social intelligence rely on neural activity in similar to cortical

areas. The similarity in cortical activity during performance of cognitive and social intelligence tasks suggests that cognitive and social intelligence are not distinct forms of intelligence. The reasonably given close relationship between cognitive and social intelligence, cognitive strategies which increase academic performance, fluid intelligence, and crystallized intelligence are also likely to improve social intelligence. Training teachers about the cognitive processes which are important for academic achievement and intelligence so that these strategies can be taught to students appears to be a critical change that would improve education. Finally, continued research on the effects of cognitive training on academic achievement and intelligence along with the accompanying neural changes promises to become an exciting era leading to synthesis of education, cognitive science, and neuroscience.

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